Evolution of the texture of low-carbon microalloyed pipe steel in the seamless pipe manufacturing process

Cite as: AIP Conference Proceedings **1785**, 040053 (2016); https://doi.org/10.1063/1.4967110
Published Online: 18 November 2016

I. U. Pyshmintsev, I. N. Veselov, A. A. Yakovleva, M. L. Lobanov, and S. V. Danilov

Evolution of the Texture of Low-Carbon Microalloyed Pipe Steel in the Seamless Pipe Manufacturing Process

I. U. Pyshmintsev [1, a)], I. N. Veselov [1, b)], A. A. Yakovleva [1, c)] M. L. Lobanov[2, d)], S. V. Danilov [2, e)]

[1]*ROSNITI JSC, 30 Novorossiiskaya Str., Chelyabinsk, 454139, Russia.*
[2]*Boris Yeltsin Ural Federal University, 19 Mira Str., Ekaterinburg, 620002, Russia.*

[a)]PyshmintsevIU@sinara-group.com
[b)]Corresponding author: VeselovIN@sinara-group.com
[c)]YakovlevaAA@sinara-group.com
[d)]m.l.lobanov@urfu.ru
[e)]s.v.danilov@bk.ru

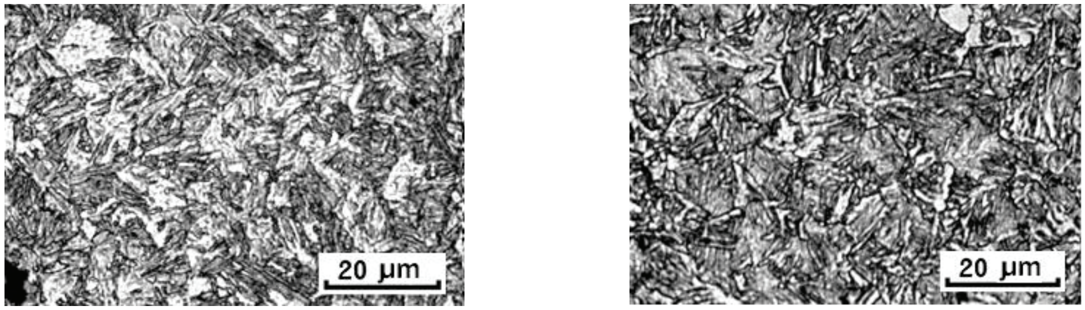
Abstract. A method of orientation microscopy (with the application of the EBSD technique) is used in investigation of the microstructure and texture in steel 0.08 % C-Cr-Mo-V formed at different stages of the seamless pipe manufacturing process, namely, after hot finishing and after full quenching with subsequent high-temperature tempering. It is shown that, at the final stage of hot finishing followed by heat treatment, the texture is represented by four scattered orientations. The found texture inheritance in the investigated material is presumably related to reproduction of special circa Σ3 boundaries between crystal grains at each phase transition.

Since 1990s much attention has been given to development of new grades of pipe steels. The longevity and reliability of pipes used in outfitting oil and gas fields are to a great extent determined by a judicious approach to the choice of steel grades and treatment methods. In view of the high water cut at many mature oil fields, the problem of corrosion failure of pipelines acquires all the greater importance [1]. In this connection, in outfitting hydrocarbon deposits, along with carbon steel pipes made to, e.g., GOST 8731 [2], pipes with higher corrosion resistance and operating reliability manufactured according to originally developed specifications started finding a wide application. Here, the basic and special features of tubular goods are attained due to task-oriented alloying of steels. As a result, compositions and strengthening heat treatment methods for carbon (type 0.20 % C), microalloyed (0.20% C-V) and low-alloyed (0.09% C-Mn-Si-V) steel grades were proposed. In the last decade, besides the above steels, more expensive compositions of low-carbon microalloyed steels were developed, namely, 0.06 % C-Cr-0.1 % V, 0.13 % C-Cr-V, 0.08 % C-Cr-Mo etc., with chromium as the main alloying element ensuring high resistance in the carbonate environment [1].

It is obvious that steels with a considerably lower carbon content, having lower strength and operated under different conditions, must display other specific relations between their operating properties and microstructure. Besides, such steels are known for specific microstructure formation. As practice shows, their microstructure components (martensite, bainite, ferrite) are hard to identify by the optical microscopy methods (Fig. 1).

The samples for investigation were taken from a hot-finished seamless line pipe manufactured from low-carbon microalloyed steel 0.08 % C-Cr-Mo-V.

Mechanics, Resource and Diagnostics of Materials and Structures (MRDMS-2016)
AIP Conf. Proc. 1785, 040053-1–040053-4; doi: 10.1063/1.4967110
Published by AIP Publishing. 978-0-7354-1447-1/$30.00



(a) (b)

FIGURE 1. Microstructure of 0.08 % C-Cr-Mo-V steel samples after quenching from different temperatures: a – 860 °C; b – 910 °C

One of the key operations in the process of manufacturing seamless line pipes is hot finishing, which, besides a change in geometrical dimensions, contributes to the arrangement of a certain texture in the material, and this texture, in its turn, through an inheritance mechanism, significantly affects the orientation-dependent properties of a finished product. As a result, there arises a problem of obtaining information about material texture evolution in the process of hot finishing. A solution to the said problem is facilitated by modern orientation microscopy methods, particularly, the electron backscatter diffraction technique, or EBSD, allowing more detailed analysis of microstructure and texture from the point of view of all its components, at both micro- and macro-levels [3].

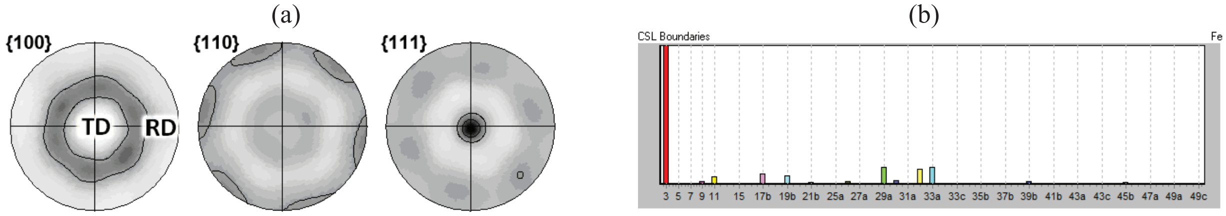
Crystallographic texture results from material deformation and/or heat treatment present in practically all industrial technologies and changes in the further processes of diffusional-phase or structural transformations. The well-pronounced texture in the bulk of the whole article (integral structure) defines the anisotropy of its physical and mechanical properties. In case a complex multi-component texture ("textureless" state) is formed as a result of treatment, the presence and quality (morphology, geometry) of its individual components often take priority.

In this study, with the application of orientation microscopy (the EBSD technique), the structural and textural states of 0.08 % C-Cr-Mo-V steel samples were investigated at different stages of seamless pipe manufacturing: 1) after hot finishing; 2) after heat treatment including quenching and high-temperature tempering.

It is shown that, at the final stage of hot finishing, the steel structure throughout the full pipe wall thickness consists of non-recrystallized austenite grains elongated in the direction of rolling. In the process of cooling after hot finishing, equilibrium $\gamma \rightarrow \alpha$ transformation takes place with grain nucleation and growth either to the austenite grain boundary or to collision of one with the other. The thus formed ferritic structure is characterized by a presence of scattered axial texture with the <111> axis directed along the pipe generatrix. The above texture may be presented as a set of four scattered components: two from {112}<110> and two from {110}<112> (Fig. 2, Table 1).

On the assumption of ferritic orientations originating from austenitic ones, meeting the Kurdyumov-Sachs orientational relation ($\{111\}\gamma \parallel \{110\}\alpha$, $\langle 110\rangle\gamma \parallel \langle 111\rangle\alpha$), the γ-phase deformation texture may be presented as a set of four orientations: two from {112}<111> and two from {111}<112> (Table 1).

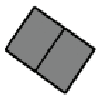
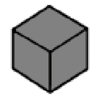
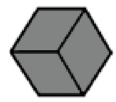
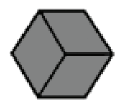
(a) (b)



(c) (d)

FIGURE 2. 0.08 % C-Cr-Mo-V steel microstructure and texture after hot rolling: a – orientational map colored in the rolling direction (RD); b – orientational map colored in the transverse direction (TD); c – straight pole figures from the area reaching throughout the full pipe wall thickness; d – the frequency of registration of special boundaries in the area reaching throughout the full pipe wall thickness

TABLE 1. A scheme of phase transformation texture formation from austenitic texture meeting the Kurdyumov-Sachs orientational relations ({111}γ || {110}α, <110>γ || <111>α) with involvement of special Σ3 boundary

γ-phase orientations following hot rolling		Experimentally observed α-phase orientations	
Variant 1			
	{112}<111>		{112}<110>
Σ3 (Rotation through 60°, axis <111>)		Σ3 (Rotation through 60°, axis <111>)	
	{112}<111>		{112}<110>
Variant 2			
	{111}<112>		{110}<112>
Σ3 (Rotation through 60°, axis <111>)		Σ3 (Rotation through 60°, axis <111>)	
	{111}<112>		{110}<112>

After quenching, the steel structure presents a mixture of lath martensite and lamellar ("lenticular") bainite. The martensite and bainite volume ratio may vary depending on the austenite chemical composition (mostly in terms of carbon content) and the rate of cooling. The martensite-bainite mixture is characterized by the presence of a texture similar to but more strongly pronounced than that of ferrite formed at slow cooling. In the process of high-temperature tempering, the morphology of structural components and, respectively, their texture, remain practically unvaried (Fig. 3a, b).

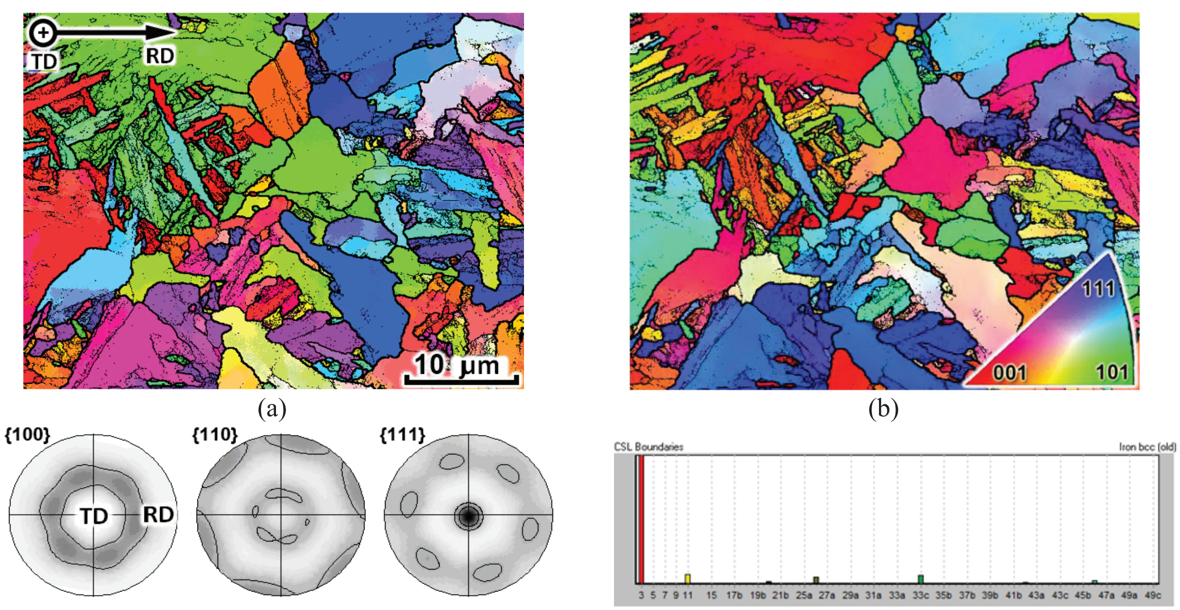


FIGURE 3. 0.08% C-Cr-Mo-V steel microstructure and texture after quenching and tempering: a – orientational map colored in the rolling direction (RD); b – orientational map colored in the transverse direction (TD); c – straight pole figures from the area reaching throughout the full pipe wall thickness; d – the frequency of registration of special boundaries in the area reaching throughout the full pipe wall thickness

Understandably, the applied EBSD investigation technique has allowed us to identify the structural components observed in steel 0.08 % C-Cr-Mo-V after different treatment modes (e.g., to separate the bainitic and martensitic components), which was practically unattainable by optical microscopy.

CONCLUSION

The established fact of textural inheritance in steel 0.08 % C-Cr-Mo-V, whose heat treatment included binary phase recrystallization, is presumably related to the formation of austenitic deformation texture, and it may be attributed to the reproduction of specific disorientations – special circa Σ3 boundaries (Table 1) at each phase transition between crystal grains.

ACKNOWLEDGMENTS

The work was done with the equipment of the "Structural Methods for Analyzing the Properties of Materials and Nanomaterials" laboratory of the Common Use Center of the Ural Federal University, with the financial support under the RF Government Regulation No. 211, Contract No. 02.A03.21.0006, and within the framework of the governmental assignment of the RF Ministry of Education and Science, Project No. 11.1465.2014/K. The authors are thankful to PAO TMK for support and cooperation in organizing the investigation.

REFERENCES

1. V. V. Zavyalov, The problems of operational pipeline reliability in the late stages of field exploitation (OAO "VNIIOENG", Moscow, 2005).
2. GOST 8731-93, Steel hot-finished seamless pipes. Specifications (M.: Standards Publishers, 1993).
3. M. L. Lobanov, A. S. Yurovskikh, N. I. Kardonina, G. M. Rusakov, *Methods of investigations material's texture. Work-book* (Ural University Publishers, Ekaterinburg, 2014).